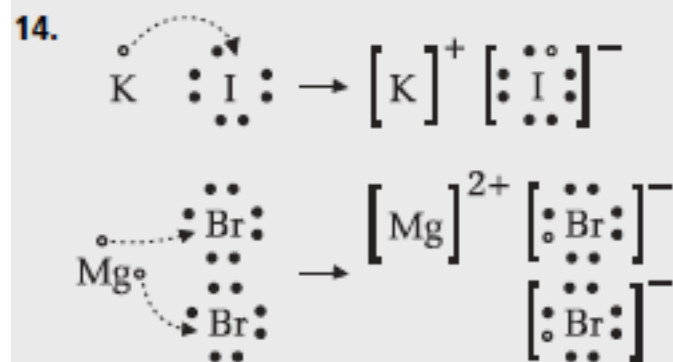


1. (b)
2. (e)
3. (c) and (d)
4. (c)
5. (e)
6. (a) and (c)
7. (c)
8. (d)
9. (b)
10. (b)
11. The three properties of ionic and molecular compounds that differ are boiling temperature, electrical conductivity, and hardness. For ionic compounds: high boiling points, high electrical conductivity in liquid state, hard, and brittle. For molecular compounds: low boiling points, low electrical conductivity, soft.
12. In electron dot diagrams of atoms, some electrons are drawn in pairs when the atom has more than four valence electrons. This corresponds to the actual placement of electrons in energy sublevels in atoms. Each sublevel can hold two electrons, and until all four sublevels are half-filled, one electron is placed into each of the sublevels. When more than four valence electrons are present, pairs will form in the energy sublevels.
13. Most ionic compounds are composed of both metals and non-metals. Molecular compounds usually contain only non-metals.



15. (a) nickel(II) oxide

(b) sulfur trioxide

(c) potassium carbonate

(d) tetraphosphorus decaoxide

(e) sodium perphosphate

(f) ammonium hydrogen carbonate

(g) dinitrogen monoxide

(h) sodium hypochlorite

(i) silicon dioxide

16. (a) $\text{HgS}(s)$

(b) $\text{Ca}(\text{OH})_2(s)$

(c) $\text{Cl}_2(g)$

(d) $\text{SO}_2(g)$

(e) $\text{CsF}(s)$

(f) $\text{NH}_4\text{NO}_2(s)$

(g) $\text{MnO}_2(s)$

(h) $\text{Pb}(\text{SO}_3)_2(s)$

(i) $\text{CaOOC}(\text{COO})(s)$

- 17.** Intramolecular forces exist between atoms in a molecule, such as the covalent bonds between the hydrogen and oxygen atoms in water. Intermolecular forces exist between molecules, such as the hydrogen bonds that hold water molecules together.
- 18.** Predicted bond angles are based on maximum separation. In a tetrahedral, the maximum angle that can be formed between bonds is 109.5° . In a trigonal planar molecule, that maximum is 120° . These theoretical bond angles would be seen if all of the atoms in a molecule (and therefore the repulsions) were equal. But, lone pairs repel each other to a greater degree than a lone pair-bonding pair and even more so than bonding pairs, so the actual bond angles are affected by the differing degrees of repulsion.
- 19. (a)** Alkanes are tetrahedrals.
- (b)** They are symmetrical molecules, so they are non-polar. London (dispersion) forces would exist between the molecules.
- (c)** Since alkanes are symmetrical, they are non-polar.
- (d)** Since they all contain the same number of electrons, one could expect that their boiling points would be similar. In reality, however, the boiling point depends not only on the number of electrons, but also on the efficiency of molecular packing. The better they pack, the higher the boiling point.
- 20. (a)** Radon and krypton are both noble gases, held together only by London (dispersion) forces. Since radon has more electrons, it will have a higher boiling point.
- (b)** Hydrogen chloride, HCl(g) is a polar molecule, so molecules of HCl(g) are held together with dipole-dipole forces, which are stronger than the London (dispersion) forces holding atoms of argon together.

(c) Methane, $\text{CH}_4(\text{g})$, is a tetrahedral molecule. Although the individual bonds are polar, the dipoles cancel in

this symmetrical molecule, making methane non-polar.

(d) To determine the shape of hydrogen sulfide, consider the bonding elements around sulfur. Sulfur has two lone pairs and will form two single bonds with the hydrogen atoms. This is VSEPR class AX_2E_2 , a bent molecule.

21. Lone pairs of electrons around the central atom of a molecule will reduce the bond angle between two bonding pairs of electrons.
22. In ionic compounds there are no distinct pairs or groups of atoms that can be identified as "molecules." Due to their opposite charge, an attractive force exists between every negative ion and every positive ion that surrounds it, and vice versa.
23. Chlorine (Cl_2) consists of two chlorine atoms that share an electron pair. Each individual chlorine atom has seven valence electrons before bonding. Oxygen (O_2) molecules consist of two oxygen atoms that share two electron pairs. Each individual oxygen atom has six valence electrons. Nitrogen (N_2) molecules consist of two nitrogen atoms that share three electron pairs. Each individual nitrogen atom has five valence electrons. The double and triple bonds form to complete a stable octet for each atom.
24. A special model was needed to explain the unique properties of metallic compounds, which are very different from those of molecular compounds.

25. CO_2 and CS_2 are linear non-polar molecules. Dispersion forces are the only intermolecular forces that determine their melting points and boiling points. Molecules of CS_2 (38 electrons) are larger than molecules of CO_2 (22 electrons). Therefore, London (dispersion) forces are stronger in CS_2 , and its boiling point is higher than the boiling point of CO_2 .
26. The difference in electronegativities can be used to predict the type of bond that will form between two atoms of any two elements. If the difference is greater than 1.7, the bond will most likely be ionic. If it is less than 0.5, the bond will likely be covalent and slightly polar. If the difference falls between 0.5 and 1.7, the bond is polar covalent. If there is no difference, the bond will be non-polar covalent.
27. The bond would be expected to be strong and cause the solid to form an ionic crystal lattice with a high melting point. The bond would be 30% covalent.
28. Dipole-dipole attractions are between molecules that have a permanent positive charge on one end and a negative charge on the other end. London (dispersion) forces are between molecules that have a temporary dipole caused by vibration of electrons, setting up an uneven distribution of charge. For a small molecule, such as hydrogen chloride, the dipole-dipole forces are stronger than the dispersion forces. However, dispersion forces can be quite large if there are a large number of electrons spread over a large molecule.
29. In graphite, each carbon atom forms three strong covalent bonds with three other carbons in a trigonal planar pattern. These bonds give a layered structure. The fourth bond, between the layers, is longer and weaker than the other three. It is easily broken and allows the layers to

slide by one another, making it a good lubricant. Because of the strong covalent network bonds, graphite does not break down at high temperatures as most lubricants do.

30. *Similarities:* Both generally have high melting temperatures. Both are hard but covalent network solids are harder. Both involve bonding between atoms. Both generally have a high boiling point and are insoluble in water.

Differences: Metals are malleable and ductile and network solids are brittle. Metals conduct electricity and network solids are insulators.

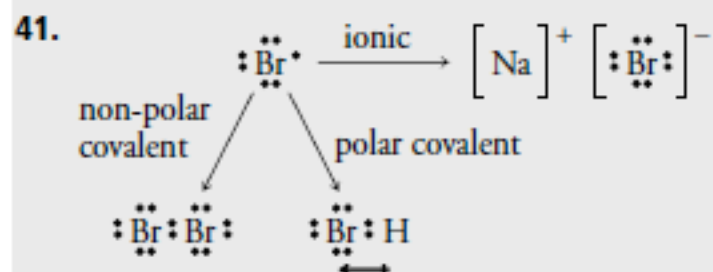
31. When pure molecular substances boil, the intramolecular covalent bonds between the atoms do not break. It is the intermolecular bonds between the particles that must break, and, therefore, the boiling point is an indication of the strength of intermolecular attractive forces.
32. The strength of dispersion factors is affected by the number of electrons in the molecule and the shape of the molecule.
33. Hydrogen bonds require a hydrogen atom bonded to a highly electronegative atom, such as oxygen, nitrogen, or fluorine, and to a lone pair of a nearby electronegative atom.
34. Hydrogen bonds have their maximum strength when they are oriented along a line from the centre of one oxygen atom, through the covalently bonded hydrogen atom, and to the centre of the oxygen atom of the next water molecule. This occurs in ice.
35. Water forms hydrogen bonds between the hydrogen atoms in one water molecule and the oxygen atom in another. Methane does not form hydrogen bonds, and, therefore, has a lower boiling point. Ammonia forms hydrogen bonds between the hydrogen atoms in one ammonia molecule and the nitrogen atoms in another.

However, the bonds between nitrogen and hydrogen atoms in ammonia are less polar than O—H bonds, and, therefore, ammonia has a lower boiling point.

- 36.** Metals are malleable because the layers in their structure can move without breaking the array, since freely moving valence electrons continue to exert a uniform attraction on the positive ions in the layers.
- 37. (a)** The shape of ionic crystals is determined by the relative size and charge of the ions in the crystal.
- (b)** Ionic crystals do not conduct electricity (unless dissolved or melted) and are brittle. They have smooth sides and a characteristic shape. When struck, the crystal may cleave cleanly into smaller crystals of the same shape.
- (c)** In order to conduct electricity, there must be freely moving charged particles. In a crystal, the ions are fixed, so cannot conduct electricity. The remainder of the properties are due to the structure of the crystal. Ions will pack into a crystal shape based on the relative size and charge of the ions, leading to a specific shape. It must be neutral in charge, so the faces will be smooth. When struck, the like-charged ions will be forced beside each other, leading to the cleaving of the crystal.
- 38.** In order to melt a substance, the intermolecular forces holding the molecules/atoms or ions together must be broken. The stronger the intermolecular forces, the greater the amount of energy that must be put in to melt the substance. This amount of energy is measured as the kinetic energy in the molecules, or the melting point.
- 39.** In the molten state, ions are free to move and can act as charge carriers. However, in the solid state, ions are held in rigid positions in the crystal lattice and cannot move to carry an electric charge.

Answers to Applying Concepts Questions

40. (a) mostly ionic
 (b) polar covalent
 (c) metallic
 (d) non-polar covalent



42. The electronegativity difference for LiBr is 1.98 and for LiI is 1.68. LiBr should have more ionic character than LiI. Thus, LiBr should have a higher melting point than LiI.
43. Electronegativities: N (3.04), H (2.20), F (3.98), I (2.66), Cl (3.16)
- (a) N is more electronegative, and it is the negative end of the dipole ($\text{N} \leftarrow \text{H}$).
- (b) F is more electronegative, and it is the negative end of the dipole ($\text{F} \leftarrow \text{N}$).
- (c) Cl is more electronegative, and it is the negative end of the dipole ($\text{I} \rightarrow \text{Cl}$).
44. Electronegativities: F (3.98), Cl (3.16), Br (2.96), I (2.66), Si (1.50), P (2.19), S (2.58)
- (a) The order of increasing bond polarity is $\text{Cl}-\text{Cl}$, $\text{Br} \rightarrow \text{Cl}$, $\text{Cl} \rightarrow \text{F}$. The arrow points toward the element with a partial negative charge. $\text{Cl}-\text{Cl}$ is non-polar.

- (b) The order of increasing bond polarity is Si—Si, S → Cl, P → Cl, Si → Cl. The arrow points toward the element with a partial negative charge. Si—Si is non-polar.
45. First determine whether the solid can conduct electricity. If it can conduct electricity as a solid, it is a metallic compound. You can confirm this if it has lustre and is malleable and ductile. If the solid can conduct an electric current when it is dissolved in water, it is an ionic compound. If the compound cannot conduct electricity, heat the solid to determine the melting point. A high melting point will indicate a network solid. If the boiling point is low, the compound is molecular.
46. The ammonium ion is symmetrical, having a tetrahedral shape, and is therefore non-polar because the bond polarities cancel each other. Since the ammonia molecule has only three hydrogen atoms, it forms a pyramidal shape and is not symmetrical. Therefore, the bond polarities do not cancel each other and the molecule is polar.
47. Agree. All molecules have random motion due to their kinetic energy. If there were no intermolecular forces to hold them together, collisions with each other would bounce them apart and they would remain as gases. It is only the intermolecular forces that hold them together in the liquid or solid state.
48. Boiling point generally increases down a group, because as the number of electrons increases, the strength of the London (dispersion) forces increases. The expected trend in boiling points is $\text{H}_2\text{O} < \text{H}_2\text{S} < \text{H}_2\text{Se}$. However, H_2O does not follow the trend because there is hydrogen bonding in H_2O , but not in the others.

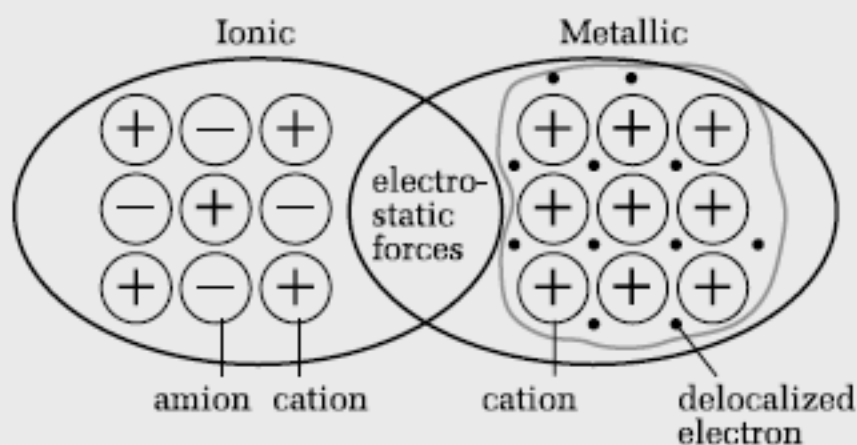
- 49.** Covalent bonds are the simultaneous attractions between the nuclei and electrons of two or more atoms.
- (a)** In non-polar covalent bonds, the attractions of the different nuclei of the atoms for the electrons are the same.
 - (b)** In polar covalent bonds, the nucleus of one of the atoms attracts the bonding electrons more strongly than the nuclei of the other atom does. In the O—H bond in a water molecule, the oxygen nucleus attracts the pair of electrons between the two atoms more than the hydrogen nucleus does. Therefore, the O—H bond in water is polar covalent.
 - (c)** In ionic bonds, ions of opposite charges attract each other. Particles in ionic compounds cannot properly be termed molecules, so water cannot be ionic.
- 50. (a)** London (dispersion) forces are temporary attractive forces that form between all molecules due to an imbalance in charge that induces an opposite charge in nearby molecules. They are the only intermolecular force that exists between non-polar molecules and noble gases.
- (b)** Dipole-dipole forces are attractive forces that exist between the oppositely charged ends of polar molecules.
 - (c)** Hydrogen bonds are extremely strong dipole-dipole forces that exist between molecules where hydrogen is bonded directly to either oxygen or fluorine or nitrogen. This best describes the forces between water molecules in a glass of water.
 - (d)** Intermolecular forces are attractive forces that exist between atoms, molecules, or ions. They must be broken in order to change the state of the substance.
 - (e)** Intramolecular forces exist between atoms within the same molecule.

51. (a) A metallic element has metallic lustre, is a good conductor of electricity and heat, is malleable and ductile, and melts at a relatively high temperature.
- (b) A metallic element reacts with a non-metallic element to form an ionic compound. It reacts with an acid to produce hydrogen gas. (Of course only active metals will do this, but this is a reaction with which students should be familiar. A metallic element also reacts with oxygen to form oxides that dissolve in water to form strong bases. It reacts with chlorine to form salts that conduct electricity in the molten state or in an aqueous solution.)
52. (a) The percent ionic character increases with increasing ΔEN . Thus, the greater the electronegativity difference between the elements, the more ionic character a bond has.
- (b) Chlorine, Cl_2 , has 0% ionic character. This implies that the two chlorine nuclei attract the pair of electrons between them equally. The bond is described as a non-polar covalent bond.
- (c) The trend of the graph suggests that there is no compound with 100% ionic character. This implies that the model for covalent bonding applies to all compounds. Even for ionic compounds with large electronegativity differences, complete electron transfer (as suggested by the ionic bonding model) is unlikely.
- (d) The arbitrary cutoff suggests that bonding is a continuum with the ionic bond on one extreme and the non-polar covalent bond on the other extreme. Most of the bonds are somewhere in between and have at least a partial polar covalent nature. (Thus, all bonds are considered to be the simultaneous attractions between the nuclei and electrons of two or more atoms.)

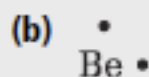
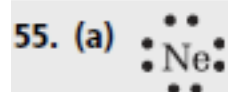
53. Fluorine has the highest electronegativity and so forms very strong bonds with other compounds. Therefore, from a bonding point of view, fluorine is difficult to isolate. It is also extremely poisonous. (Once prepared, the fluorine gas attacks water and vessels. It cannot be contained, and it reacts with moisture in the air to form

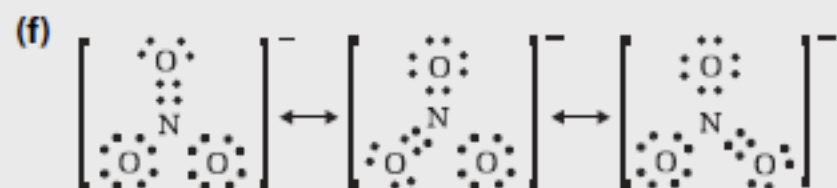
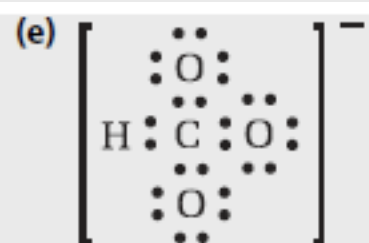
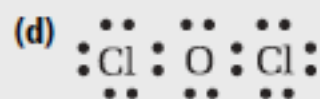
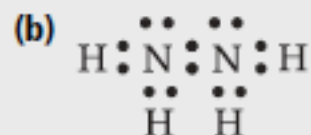
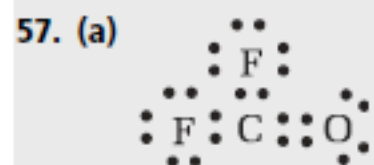
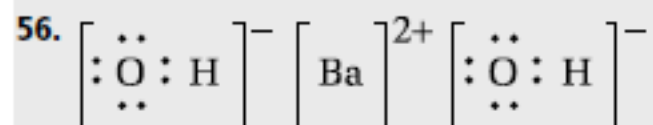
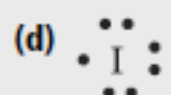
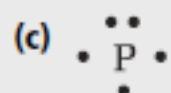
deadly hydrogen fluoride gas. The poisonous nature of hydrogen fluoride, which injured many people who worked with the gas in the past, makes the safe isolation of fluorine more remarkable. Moisson himself reported four delays in his studies of the electrolysis due to severe poisoning. He captured the fluorine gas in a platinum-iridium alloy U-tube, which was cooled to reduce the rate of attack by fluorine on the vessel walls. Thus, the Nobel Prize was given to Moisson for his dedication and courage working with extremely toxic materials to forward the cause of science.)

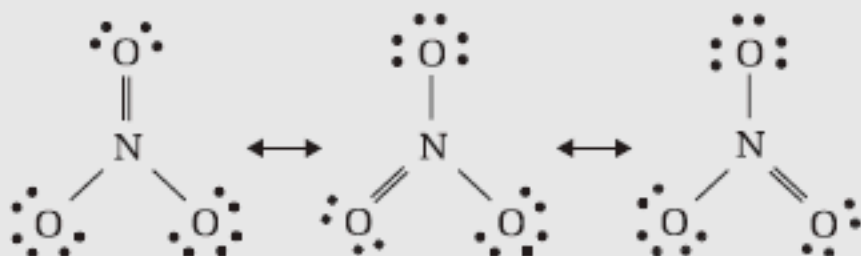
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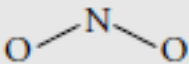


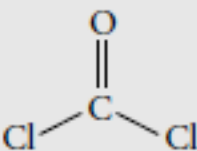
Answers to Solving Problems Questions

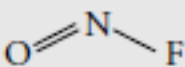


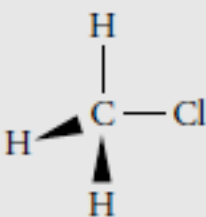


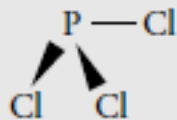


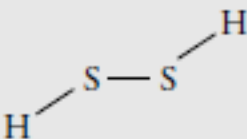
58. (a)  (bent)

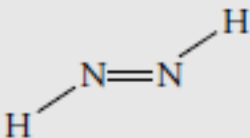
(b)  (trigonal planar)

(c)  (bent)

(d)  (tetrahedral)

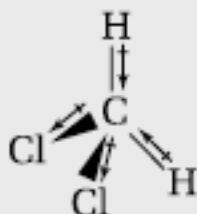
(e)  (pyramidal)

(f)  (bent)

(g)  (bent)

59. a, b, c, d and e are all polar.

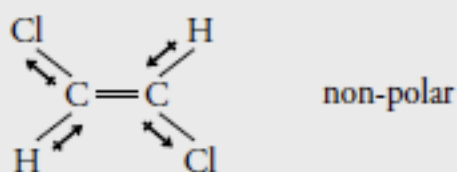
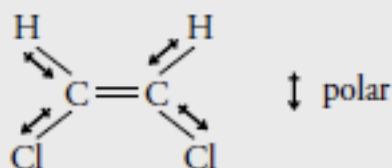
60.



The two atoms of chlorine and the two atoms of hydrogen are arranged in a tetrahedral shape around the carbon. The C—Cl bonds are more polar than the C—H bonds. The direction of the polarities indicates that the Cl

side of the molecule is slightly negative and the H side is slightly positive, so the molecule is polar.

61.

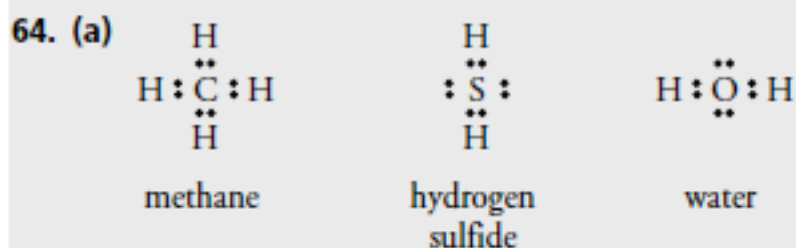


This molecule is trigonal planar. There are two isomers; one is polar, the other is non-polar.

Answers to Making Connections Questions

62. Student answers will depend on the type of research and application selected. Possible applications include drug delivery, protective films, superconductors, and nanotubes. Students may be divided into groups to research specific applications. Each group can then present their information to the class.

63. (a) Iron is held together with metallic bonds. The properties of metallic bonds include ductility and malleability. This allows iron to be used in many applications that require strength and some flexibility. Iron(III) oxide is an ionic compound. Although it will have a high melting and boiling point, ionic compounds are brittle and can be easily cleaved into smaller pieces.
- (b) One possible difference is that the ratio and size of the ions is different between iron(III) oxide and aluminium oxide. This would lead to a different crystal structure and perhaps different properties.



- (b) The intermolecular forces holding these molecules together differ, and so will their boiling points. Methane is non-polar, held together only by the weakest intermolecular forces, London (dispersion) forces, so methane will have the lowest boiling point. Water is held together by the strongest intermolecular forces, hydrogen bonds, so water will have the highest boiling point. Hydrogen sulfide gas is polar and held together with dipole-dipole forces, so it will have a boiling point between the other two substances.
- (c) There are two factors affecting the boiling points of these substances. The polarity of the molecules is slightly less, so the dipole-dipole forces will be reduced somewhat; however there are more electrons

in H_2Te than in H_2Se (and even H_2S), which will lead to stronger London (dispersion) forces. In reality, the boiling point of H_2Te is greater than H_2Se , which is greater than H_2S .

- (d) Using the differences in boiling points, the sour gas could be cooled. When the temperature falls below the boiling point of hydrogen sulfide, it can be removed as a liquid, leaving only pure methane behind.
65. (a) To separate the strands of DNA, the DNA could be heated until the hydrogen bonds are broken. This would not break the covalent bonds in the strands.
- (b) If the temperature of the protein gets too high, the hydrogen bonds in the protein will be broken, changing its shape. Since the functionality of a protein is based on its shape, if the temperature gets too high, the protein will no longer function.